Proposal to Extend SystemC-AMS with a Bond Graph Based Model of Computation

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Abstract—There is a need to improve the modelling capabilities of SystemC-AMS concerning conservative continuous time systems involving the interaction of several physical domains and the interaction with digital control components. Bond graphs unify the description of multi-domain systems by modelling the energy flow between the electrical and non-electrical components. They integrate well with block diagrams describing the signal processing part of a system. It is proposed to develop an extension to the current SystemC-AMS prototype, which shall implement the bond graph methodology as a new Model of Computation (MoC).

SystemC [1] is a C++ library, which allows to model complex digital hardware/software systems, or Systems-on-Chips (SoCs), by mapping them on communicating processes executed and synchronised by a Discrete-Event (DE) MoC based simulation kernel. Advances in processing technologies allow to make SoCs more and more feature rich and heterogeneous by integrating also analogue, RF, and Micro-Electro-Mechanical System (MEMS) components. Several attempts to extend SystemC have been done to support the design of these Analogue and Mixed-Signal (AMS)-SoCs. *SystemC-AMS* [2] provides an efficient Synchronous Data Flow (SDF) MoC to model signal processing dominated continuous time behaviours. However, when it comes to modelling conservative systems, SystemC-AMS and SystemC-A [3] use a quite low-level approach with equation setups and analysis methods similar to classic SPICE-like circuits simulators, which causes a simulation performance penalty. *SystemC-WMS* [4] uses another approach from Wave Digital Filter (WDF) theory, where analogue modules communicate by exchanging energy waves. This is implemented using SystemC hierarchical channels, which limits the simulation performance due to the scheduling of discrete events for each time step.

The goal of this work is to improve the modelling and simulation capabilities of SystemC-AMS regarding conservative continuous time components and their interaction with discrete time (digital) control components by implementing a new MoC based on the *bond graph methodology* [5]. This methodology is attractive for the design and verification of AMS-SoCs because it unifies the description of multi-domain systems. Every conservative system can be transformed from its domain specific representation (e.g., electrical circuit, mechanical multi-body system, fluidic networks, thermal networks) to a bond graph representing graphically the energy flow between generalised elements modelling energy sources, resistive/capacitive/inertial behaviour, quantity transformations (also across physical domain boundaries), and energy distribution through junctions. The link to the physical domain is kept through the units attached to the variables and parameters of the generalised elements. This allows for dimensional analysis to discover illegal element interconnexion and equations involving incompatible quantities. One main advantage of bond graphs is that they can be annotated in a systematic way with the *causality*, which visualises the computational structure (Which variables act as inputs and which as outputs?) of the bond graph and allows to sort the element equations in the right order for an efficient model execution. The assigned causalities allow some further formal checks on the model: the number of states and non-states in the system, the presence of algebraic loops during model execution, or if it is an ill-posed model. They also allow for a well integration of bond graphs with signal flow graphs.

The implementation of the bond graph based MoC will profit from the fact that SystemC-AMS is a library on top of the fully-featured C++ language. The integration and synchronisation with the other MoCs, especially the SDF MoC and the DE MoC, is needed. The strong interaction between the analogue and digital parts of a SoC requires to take into account discrete switching of the energy flows inside the bond graphs due to external signals and thus causality changes during the model execution. The research in this field of *hybrid bond graphs*, which incorporate this local switching capability, is still on-going and needs more efforts to find ways to efficiently reassign causality and to regenerate the computational model at runtime when junction switching occurs [6]. Another important aspect is to allow for hierarchical modelling thus implementing aspects of *word bond graphs* [5].

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